THE LUNAR ATMOSPHERE AND DUST ENVIRONMENT EXPLORER MISSION. L. A. Leshin[1], W. M. Farrell[1], D. H. Crider[2], R. C. Elphic[3], P. D. Feldman[4], R. Hodges[5], M. Horanyi[6], W. T. Kasprzak[1], R. Vondrak[1], S. McClard[7], B. P. Hine[3], W. S. Marshall[3], T. Morgan[8], S. Noble[8], K. Snook[9]. [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA, [2]Catholic University of America, 106 Driftwood Dr., Gibsonville, NC 27249 USA, [3]NASA Ames Research Center, Moffett Field, CA 94035-1000 USA, [4]Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218 USA, [5]University of Texas at Dallas (Emeritus), P.O. Box 4384, Frisco, CO 80443 USA, [6]LASP, Univ. of Colorado, Boulder, CO 80309-0392, USA, [7]NASA Marshall Space Flight Center, Huntsville, AL 35812 USA, [8]Science Mission Directorate, NASA Headquarters, 300 E St. SW, Washington D.C. 20706 USA.

Introduction: The top ten objectives identified in the National Research Council's report, "Scientific Context for the Exploration of the Moon" [1] include (a) determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity, and (b) determine the size, charge, and spatial distribution of electrostatically transported dust grains and assess their likely effects on lunar exploration and lunar-based astronomy. Of the many possible constituents of the tenuous lunar exosphere only four have been detected (Ar, He, Na and K), but only upper limits have been placed on others [2]. The physics behind source, transport and loss processes remains largely unknown. The existence of electrostatically lofted charged dust grains remains controversial. Imagery from the lunar surface (Surveyor) and lunar orbit (Apollo and Clementine) have been interpreted in terms of lofted dust, but are debated [3]. The Lunar Atmosphere and Dust Environment Explorer (LADEE) mission aims to fill the gaps in our knowledge concerning the tenuous lunar exosphere and the existence and character of lofted lunar dust. In so doing, LADEE will also indirectly address questions related to cold-trapping of volatiles and sputtering rates at the lunar surface.

LADEE Science Objectives: The LADEE Science Definition Team was asked to evaluate the scientific merit of fielding a small, short-duration orbital lunar mission with a limited payload focused on assessing the tenuous lunar exosphere and establishing the presence of significant lofted dust. The SDT distilled the scientific objectives as: (1) Determine the composition of the lunar exosphere and investigate the processes that control its distribution and variability – sources, sinks, and surface interactions; (2) Characterize the lunar exospheric dust environment and measure its spatial and temporal variability.

Measurement Requirements: The science objectives for the exosphere and lofted dust flow down to the following measurement requirements:

Exosphere. The exospheric measurement requirements are: measure spatial and temporal variations of known species (Ar, He, Na, K) on time scales of hours and for at least one lunation, preferably several; derive a new upper limit or a direct discovery detection for those gases plausibly present in the lunar exosphere (CH_4, CO, CO_2, N_2, H, H_2, H_2O, N, C, S, OH, all possibly from solar wind interaction with regolith, and Si, Al, Ca, Fe, Ti, and Mg from sputtering); establish the density of at least one member of the various source constituents (radiogenic, solar wind-derived, regolith, meteoric); for major constituents, establish the spatial and temporal variability in abundance.

Dust. Electrostatically charged dust grains that are lofted above the lunar surface could be responsible for the lunar horizon glow observed at sunrise and sunset on previous missions. Models of these observations, illustrated in **Figure 1**, suggest that at orbital altitudes of ~50 km the grain size would be ≤100 nm, with concentrations of ~ 10^{-4} cm^{-3}. Consequently LADEE has the following dust measurement requirements:

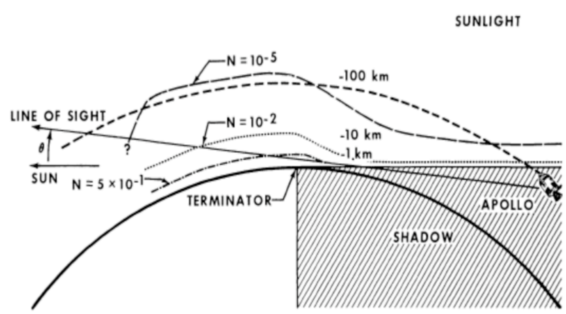

Fig. 1. Density contours of the characteristic 0.1 μm radius grains based on the photometry of images taken by Apollo astronauts from the command module [3].

obtain a lower limit or direct detection of the lofted dust from the lunar surface; identify the role of micrometeor impact by detecting the ejecta particles they produce; obtain an upper limit or direct detection of ejecta from micrometeor impacts; determine grain concentration and size a function of altitude; determine if variations in grain concentration and size result from changing plasma or micrometeor environment.

Orbit Drivers and Requirements: Many factors constrain the LADEE orbit. Gas concentrations for species such as Ar peak at the morning terminator, and densities at orbital altitudes fall with increasing latitude. These factors push the orbit to low altitudes and latitudes. Dust densities are likely to be highest at lowest altitudes, also pushing periapsis (at least) to low altitudes. A polar orbit would maximize spatial coverage, but minimizes the time spent over a specific local time, such as the dawn terminator.

The LADEE concept is to co-manifest with GRAIL to eliminate the need for a dedicated launch vehicle. However, NASA is still carrying a separate launch for LADEE as an option. Co-manifesting LADEE with the GRAIL launch places a severe constraint on overall Δv, and hence on payload mass. To maximize payload and meet the requirement of repeated measurements near or at the dawn terminator, an eccentric orbit is required. For certain instruments (see below), pointing into spacecraft ram is necessary – however, pointing into the sun at the same time should be avoided. This constraint forces a retrograde orbit (like Apollo) that is low inclination and with periapsis placed at or near the dawn terminator. A substantial orbital trade study has already been performed, balancing dawn terminator crossings against fuel budget and maximum achievable payload mass. Eccentric orbits with 50 x 1350 km and 50 x 3300 km altitudes are being considered. A 50 x 50 (circular) orbit is not achievable with a nominal payload mass of ~20 kg.

Potential Instruments: Several types of instruments can address the LADEE measurement requirements. For the exosphere, these include neutral mass spectrometers (for in situ measurement of exospheric species), ion mass spectrometers (for picked-up photoions and secondary ions from surface sputtering), ultraviolet and visible spectrometers for direct identification of emission lines. For lofted dust, direct dust impact detectors (measuring the charge cloud associated with dust particle impacts) register in situ particles, while electric field detectors can indirectly detect particles by measuring either spacecraft potential change or the passage of charged grains past the antennae. Ultraviolet, visible and infrared spectrometers can also remotely sense dust, either via forward- or back-scattering, or absorption of sunlight. The short LADEE schedule (payload integration complete by May of 2010, and launch as early as March 2011) means that instrumentation must be in a mature state, either flight spares or readily qualifiable engineering models.

LADEE Spacecraft Bus: **Figure 2** shows the LADEE spacecraft bus concept, now under development at NASA Ames Research Center. The LADEE bus is an outgrowth of the the Common Modular Bus Project, which is a small, low cost spacecraft designed to deliver scientifically and technically useful payloads to a variety of locations, including Low Earth Orbit (LEO), Lunar orbit and Lunar surface, Earth-Moon Lagrange points, and Near Earth Objects (NEOs). The spacecraft bus is a lightweight carbon composite structure which incorporates a variety of recent advances in propulsion, avionics, and sensors. The key advantages of smaller spacecraft such as this are reduced costs and rapid development schedules. The current spacecraft design baseline has a dry/wet mass of 84/141 kg, with ~60 W of power provided at 1 AU by body-mounted solar arrays.

References: [1] Space Studies Board, National Research Council, (2007) National Academies Press, http://www.nap.edu/catalog.php?record_id=11954. [2] Stern, S. A. (1999) *Rev. Geophys., 37,* 4, 453-490. [3] McCoy, J. E., and D. R. Criswell (1973) *Lunar Sci. Conf.*, *5*, 2991–3005.

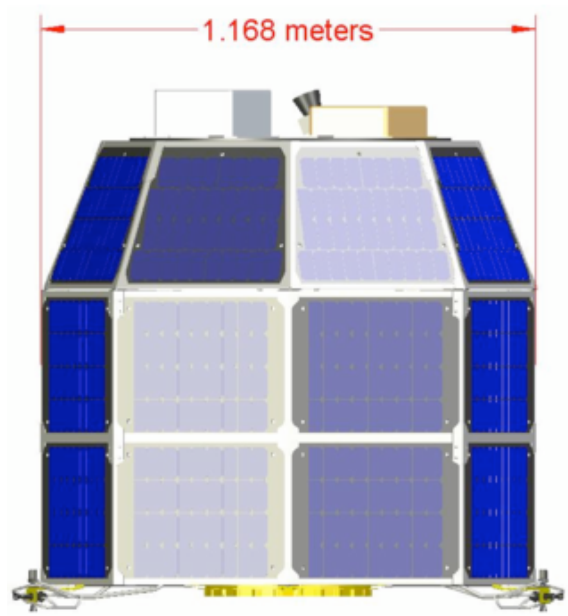

Fig. 2. The LADEE spacecraft makes use of the common modular bus architecture developed at NASA Ames Research Center. The spacecraft is ~1.2 meter in diameter.